

AMENDMENTS TO THE CLAIMS

This listing of claims will replace all prior versions, and listings, of claims in the application:

Listing of Claims

1. (Currently Amended) A bonding method for bonding objects to be bonded together in a solid phase at 500°C or less after subjecting bonding surfaces of the objects to be bonded to a hydrophilic treatment using a plasma, comprising:

a surface activation step of performing said hydrophilic treatment by means of a plasma treatment means for changing an ion strike force,

wherein said surface activation step comprises:

a physical treatment step of subjecting both said objects to be bonded to a physical treatment using said plasma having a strong ion strike force, thereby etching surfaces of the objects to be bonded, or replacing surface molecules of the surfaces with ion molecules which strike the surfaces, or making the ion molecules adhere to the surfaces, in a first half of the plasma treatment; and

a chemical treatment step of subjecting the surfaces of both said objects to be bonded to a chemical treatment using active radicals, or active ions having a weak ion strike force of said plasma of which the ion strike force is reduced by means of said plasma treatment means, in a second half of the plasma treatment after said physical treatment step, wherein said hydrophilic treatment is performed using oxygen gas as a reaction gas in said physical treatment step ~~a reaction gas containing oxygen gas in at least one of said physical treatment step and said chemical treatment step~~ so that OH groups are attached to the surfaces of both said objects to be bonded, and

after the surface activation step, the step of heating both said objects while the surfaces of both said objects are in contact, thereby covalently bonding both said objects to be bonded together.

2. (Canceled).

3. (Previously Presented) The bonding method according to claim 1, wherein a reaction gas of said chemical treatment step is oxygen gas or nitrogen gas.

4. (Previously Presented) The bonding method according to claim 1, wherein, after said physical treatment step, evacuation is performed before said chemical treatment step.

5. (Previously Presented) The bonding method according to claim 1, wherein, during or after said chemical treatment, a gas containing H₂O or H or OH groups is introduced and mixed before bonding.

6. (Canceled).

7. (Previously Presented) The bonding method according to claim 1, wherein said physical treatment step and said chemical treatment step are performed without exposure to the atmospheric air.

8. (Canceled).

9. (Withdrawn) The bonding method according to claim 1, wherein said plasma treatment means for changing the ion strike force comprises a plasma electrode including an object-to-be-bonded holding electrode and a counter surface electrode which are provided at two positions and can be used for said plasma electrode alternatively,

a power supply is applied to said object-to-be-bonded holding electrode to generate a low-pressure plasma, thereby performing a plasma treatment for performing said physical treatment,

and thereafter, said power supply is applied to said counter surface electrode to reduce the ion strike force, thereby performing a plasma treatment for promoting said chemical treatment.

10. (Withdrawn) The bonding method according to claim 1, wherein said plasma treatment means for changing the ion strike force comprises an RF plasma power supply capable of adjusting a Vdc value,

said Vdc value of said RF plasma power supply is changed in said second half of the plasma treatment to reduce the ion strike force of a low-pressure plasma so that a plasma treatment for promoting said chemical treatment is performed.

11. (Withdrawn) The bonding method according to claim 1, wherein said plasma treatment means for changing the ion strike force comprises a pulsed-wave plasma power supply capable of adjusting a pulse width,

said pulse width of said a pulsed-wave plasma power supply is changed in said second half of the plasma treatment to reduce the ion strike force of a low-pressure plasma so that a plasma treatment for promoting said chemical treatment is performed.

12. (Previously Presented) The bonding method according to claim 1, wherein said plasma treatment means for changing the ion strike force comprises a first and a second low-pressure plasma emitting means each of which emits a low-pressure plasma having a different ion strike force; and means for switching between said first and said second low-pressure plasma emitting means,

a power supply is applied to an object-to-be-bonded holding electrode of said first low-pressure plasma emitting means in said first half of the plasma treatment to generate a low-pressure plasma, thereby performing a plasma treatment for performing said physical treatment,

in said second half of the plasma treatment, said first low-pressure plasma emitting means is switched to said second low-pressure plasma emitting means which traps plasma ions generated in another room and emits radicals, thereby reducing the ion strike force so that a plasma treatment for promoting said chemical treatment is performed.

13. (Withdrawn) The bonding method according to claim 1, wherein said plasma treatment means for changing the ion strike force is means for switching between a low-pressure plasma and an atmospheric-pressure plasma,

after subjecting said surfaces of the objects to be bonded to said physical treatment with an ion strike force enhanced by said low-pressure plasma,

the ion strike force is reduced with said atmospheric-pressure plasma so that a plasma treatment for promoting said chemical treatment is performed.

14. (Previously Presented) The bonding method according to claim 1, wherein a reaction gas in said chemical treatment step is a mixed gas containing oxygen gas and nitrogen gas.

15. (Previously Presented) The bonding method according to claim 1, wherein a plasma reaction gas in said chemical treatment step is switched from a reaction gas containing oxygen gas in said physical treatment step to a reaction gas containing nitrogen gas during a plasma treatment using a reduced ion strike force in said second half of the plasma treatment.

16. (Previously Presented) The bonding method according to claim 1, wherein, during said bonding, a voltage is applied between both said objects to be bonded so that said objects to be bonded are bonded together in a solid phase while being heated.

17. (Previously Presented) The bonding method according to claim 1, wherein at least one of said objects to be bonded is made of Si, SiO₂, glass or ceramic.

18. (Previously Presented) The bonding method according to claim 1, wherein said object to be bonded is a wafer or a chip cut off from a wafer.

19. (Withdrawn) A device, such as a semiconductor device, an MEMS device or the like, which is produced using the bonding method according to claim 1.

20. (Withdrawn) A surface activating unit for subjecting bonding surfaces of objects to be bonded to a hydrophilic treatment using a plasma for bonding said objects to be bonded together in a solid phase at 500°C or less, said unit comprising:

a plasma treatment means which can change an ion strike force for performing a chemical treatment step of subjecting the surfaces of both said objects to be bonded to a chemical treatment using active radicals, or active ions having a weak ion strike force of said plasma of which the ion strike force is reduced by means of said plasma treatment means, in a second half of the plasma treatment

after a physical treatment step of subjecting both said objects to be bonded to a physical treatment using said plasma having a strong ion strike force, thereby etching the surfaces of the objects to be bonded, or replacing surface molecules of the surfaces with ion molecules which strike the surfaces, or making the ion molecules adhere to the surfaces, in a first half of the plasma treatment,

wherein said plasma treatment means performs said hydrophilic treatment using a gas containing oxygen gas as a reaction gas in at least one of said physical treatment step and said chemical treatment step, said hydrophilic treatment ~~is~~ being performed using a reaction gas containing oxygen gas in at least one of said physical treatment step and said chemical treatment step so that OH groups are attached to the surfaces of the objects.

21. (Canceled)

22. (Withdrawn) The surface activating unit according to claim 20, wherein a reaction gas of said chemical treatment step is oxygen gas or nitrogen gas.

23. (Withdrawn) The surface activating unit according to claim 20, wherein, after said physical treatment step, evacuation is performed before said chemical treatment step.

24. (Withdrawn) The surface activating unit according to claim 20, comprising a water gas generating means, wherein, during or after said chemical treatment, a gas containing H₂O or H and OH groups is introduced and mixed before bonding.

25. (Withdrawn) The surface activating unit according to claim 20, wherein a reaction gas of said physical treatment step is different from a gas of said chemical treatment step, and is Ar or CF₄.

26. (Withdrawn) The surface activating unit according to claim 20, wherein said physical treatment step and said chemical treatment step are performed without exposure to the atmospheric air.

27. (Canceled).

28. (Withdrawn) The surface activating unit according to claim 20, wherein said plasma treatment means for changing the ion strike force comprises a plasma electrode including an object-to-be-bonded holding electrode and a counter surface electrode which are provided at two positions and can be used for said plasma electrode alternatively,

a power supply is applied to said object-to-be-bonded holding electrode to generate a low-pressure plasma, thereby performing a plasma treatment for performing said physical treatment,

and thereafter, said power supply is applied to said counter surface electrode to reduce the ion strike force, thereby performing a plasma treatment for promoting said chemical treatment.

29. (Withdrawn) The surface activating unit according to claim 20, wherein said plasma treatment means for changing the ion strike force comprises an RF plasma power supply capable of adjusting a Vdc value,

said Vdc value of said RF plasma power supply is changed in said second half of the plasma treatment to reduce the ion strike force of a low-pressure plasma so that a plasma treatment for promoting said chemical treatment is performed.

30. (Withdrawn) The surface activating unit according to claim 20, wherein said plasma treatment means for changing the ion strike force comprises a pulsed-wave plasma power supply capable of adjusting a pulse width,

said pulse width of said a pulsed-wave plasma power supply is changed in said second half of the plasma treatment to reduce the ion strike force of a low-pressure plasma so that a plasma treatment for promoting said chemical treatment is performed.

31. (Withdrawn) The surface activating unit according to claim 20, wherein said plasma treatment means for changing the ion strike force comprises a first and a second low-pressure plasma emitting means each of which emits a low-pressure plasma having a different ion strike force; and means for switching between said first and said second low-pressure plasma emitting means,

a power supply is applied to an object-to-be-bonded holding electrode of said first low-pressure plasma emitting means in said first half of the plasma treatment to generate a low-pressure plasma, thereby performing a plasma treatment for performing said physical treatment,

in said second half of the plasma treatment, said first low-pressure plasma emitting means is switched to said second low-pressure plasma emitting means which traps plasma ions generated in another room and emits radicals, thereby reducing the ion strike force so that a plasma treatment for promoting said chemical treatment is performed.

32. (Withdrawn) The surface activating unit according to claim 20, wherein said plasma treatment means for changing the ion strike force is means for switching between a low-pressure plasma and an atmospheric-pressure plasma,

after subjecting said surfaces of the objects to be bonded to said physical treatment with an ion strike force enhanced by said low-pressure plasma,

the ion strike force is reduced with said atmospheric-pressure plasma so that a plasma treatment for promoting said chemical treatment is performed.

33. (Withdrawn) The surface activating unit according to claim 20, wherein a reaction gas in said chemical treatment step is a mixed gas containing oxygen gas and nitrogen gas.

34. (Withdrawn) The surface activating unit according to claim 20, wherein a plasma reaction gas in said chemical treatment step is switched from a reaction gas containing oxygen gas in said physical treatment step to a reaction gas containing nitrogen gas during a plasma treatment using a reduced ion strike force in said second half of the plasma treatment.

35. (Canceled).

36. (Withdrawn) The surface activating unit according to claim 20, wherein at least one of said objects to be bonded is made of Si, SiO₂, glass or ceramic.

37. (Withdrawn) The surface activating unit according to claim 20, wherein said object to be bonded is a wafer or a chip cut off from a wafer.

38. (Withdrawn) A bonding apparatus comprising:
said surface activating unit according to claim 20; and means for bonding both said objects to be bonded together, wherein
said apparatus collectively performs from said hydrophilic treatment using said surface activating unit to said bonding using said means for bonding.

39. (Withdrawn) A bonding apparatus comprising:
said surface activating unit according to claim 20; and means for bonding both said objects to be bonded together, wherein
during the bonding, a voltage is applied between both said objects to be bonded so that said objects to be bonded are bonded together in a solid phase while being heated.